Advanced Controls and Coordination of the Road Runner and China Draw SVCs

Anders Bostrom, Member, IEEE
PGGI, FACTS
ABB, AB
Västerås, Sweden
anders.x.bostrom@se.abb.com

Joe Warner, Member, IEEE
PGGI, FACTS
ABB, Inc.
Raleigh, NC USA
joe.m.warner@us.abb.com

Martin Cameron, Member, IEEE
Substation Engineering
Xcel Energy
Denver, CO USA
martin.cameron@xcelenergy.com

***Abstract*— Due to rapid load growth in SE New Mexico, a Southwest Power Pool (SPP) transmission plan was developed through the High Priority Incremental Load Study Process (HPILS). The uncertain future and timing of both additional load growth and generation changes made dynamic shunt compensation an ideal complement to the development plan. When weak network conditions are combined with a significant penetration of induction motor load at fault clearing, the network is prone to either overvoltage or Fault Induced Delayed Voltage Recovery (FIDVR). Advanced control functions and appropriate component ratings are necessary to not only maintain transmission operation within criteria limits, but also provide an optimal dynamic response over the expected range of network configurations. Advanced control includes coordination that significantly improves the performance of supplemental control functions when electrical interaction between nearby installations exists.**

***Index Terms*— static var compensator, SVC, static var systems, SVS, reactive power, Mvar, voltage regulator, Flexible AC Transmission Systems, FACTS**

I. NETWORK CHALLENGES AND SPECIFICATION

Due to rapid load growth made up of primarily induction motors in SE New Mexico, a Southwest Power Pool (SPP) transmission plan was developed through the High Priority Incremental Load Study Process (HPILS). The original Xcel Energy *Power for the Plains* transmission expansion plan in New Mexico included a 500-MW combined cycle plant at North Loving, see Fig. 1, which was located on the west side of the SE New Mexico load pocket. The original solution provided ample voltage and var support; however, late in the process it was found that an emissions source at the desired location was not allowed due to the proximity of two national parks. After considering the required distance from the parks, the new generation site was moved to the relatively remote substation near Gaines County, Texas on the east side of the SE NM load pocket. The new generation site also came with an increased size provided by four turbines that required an additional 345-kV transmission line from Andrews County to Road Runner. Additional studies reduced the level of new generation to a single generator turbine and no firm plans for future expansion. The 345-kV line was no longer justified by installation of a single unit. Concerns arose regarding the limitations of a single unit, including yearly operating time and reduced emissions requirements.

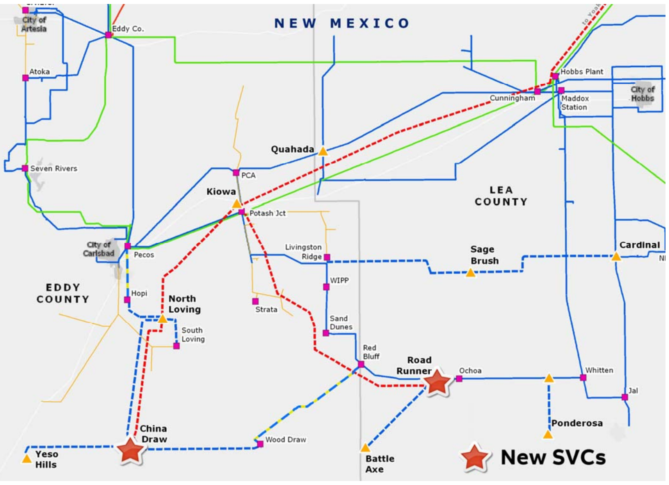

Figure 1. Transmission network in SE New Mexico

The latest studies considered the new generation being located relatively remote from the growing load pocket, particularly at Road Runner and Ochoa substations. The customer requests for additional load capability both increased and became more urgent as the study progressed. With the load increase, mechanically-switched capacitors would no longer provide the necessary compensation and low voltage was observed at multiple locations throughout the area. This prompted the study to include two SVCs, one at Road Runner to meet the demand of a specific customer requests and another at China Draw to meet forecasted load growth.

The Roadrunner and China Draw SVCs are deployed in a transmission system that is inherently weak, overcompensated and heavily loaded in relation to the prevalent fault level. When combined with a high penetration of induction motor load, Fault Induced delayed voltage Recovery (FIDVR) is a valid concern making the system prone to collapse following a

---

978-1-5386-5583-2/18/$31.00 ©2018 IEEE

disturbance. The SVCs are designed to operate in two significantly different system scenarios. When the SVCs were energized in early 2016, many of the planned upgrades were not yet in-service and the network conditions were extremely weak. For valid N-1-1 conditions at Roadrunner, the fault level could be as low as 353-MVA. At China Draw, the system was even weaker with a fault level at 272-MVA at N-0 network conditions. This puts the total SVC rating at both sites on par with the system fault level, i.e. the system to SVC Short Circuit Ratio (SCR) is approaching unity. For comparison, an SCR over 3 is recommended to ensure stability as a rule of thumb. Stability issues primarily related to power frequency parallel resonance are further exacerbated by the deployment of additional 115-kV shunt capacitors. However, there are many examples of SVCs throughout the world operating under similar conditions, where this issue is typically addressed by a combination of SVC topology selection and advanced control measures.

II. SVC RATING AND DESIGN

The SVC configuration, shown in Fig. 2, is common between the two SVC units. The transformer design is identical with a continuous rating of 110-MVA and 10-min capacitive overload capability. Thyristor Controlled Reactors (TCR) of 65-Mvar, Thyristor Switched Capacitors (TSC) of 70-Mvar and filter branches totaling 60-Mvar are common ratings for both SVCs. A single TCR can switch a TSC and maintain continuous operation, providing redundancy should one TCR be out of service. The two SVCs differ in the number of TSC branches. Provisions were made at China Draw to be future expandable with another 70-Mvar TSC.

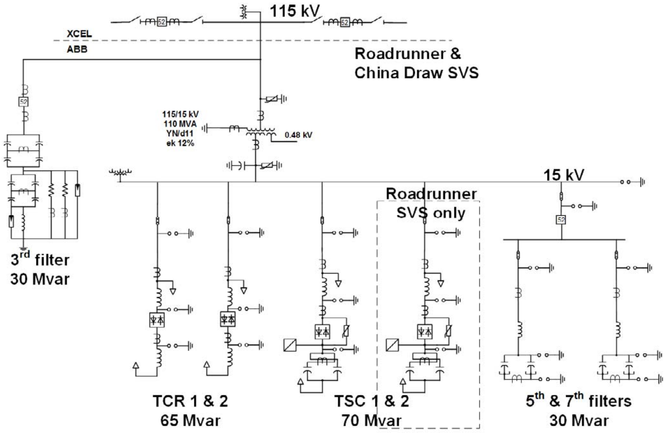

Figure 2. SVC Single Line Diagram

The SVC branch configuration is chosen to maximize the value and performance at the system location. Utilizing TSC branches improves the effective SCR level during steady-state operation. Splitting the remaining 140-Mvar into two TSC branches of 70-Mvar provides the Roadrunner unit with three roughly equal portions and provides a means for an identical China Draw SVC that is initially sized for the weaker conditions, while easily expandable in the future.

Harmonic performance is a primary driver for TCR and filter topology selection, where the requirement was to meet IEEE 519 recommended levels, including existing background distortion. In general, this is not feasible for an SVC with filters only on the medium voltage bus, especially with an existing 5th harmonic voltage exceeding 5%, which is well above the recommended level. SVC filters are generally tuned close to the TCR characteristic 5th and 7th harmonic orders to prevent TCR generated harmonics from transferring to the transmission system. The system harmonic impedance characteristics of weak, heavily shunt-compensated systems are generally difficult from a filter design perspective. Sitting behind the transformer reactance, they become de-tuned from these frequencies on the transmission network and consequently ineffective for mitigating background harmonics. To meet the requirement for total distortion at 115-kV, the required inductive vars were split between two TCR branches and a total of 60-Mvar filters were installed. The vars were split between the SVC 15-kV bus 5th and 7th order filters, and a primary 3rd order heavily damped C-type filter to remove system resonances and mitigate amplification of existing 115-kV system harmonic distortion.

The SVC has a short time overvoltage capability in its controllable range up to 1.4-pu. Undervoltage conditions in weak systems are generally accompanied by post fault overvoltage. This phenomenon is typically observed where low inertia induction motor load is prevalent, which tends to stall and trip during undervoltage conditions. At fault clearing, the load change can create post fault overvoltage conditions. Granted, much of the load in this case is large induction motors, though a significant part of the system close to the SVCs is comprised of residential air conditioning.

The Voltage-Current (VI) characteristic from the primary side of the SVC is shown in Fig. 3. The hashed area denotes short-time operation, whereas the solid blue shows the continuous range. Notice a common continuous range between the installations, where the additional TSC at Road Runner provides the capacitive overload capability.

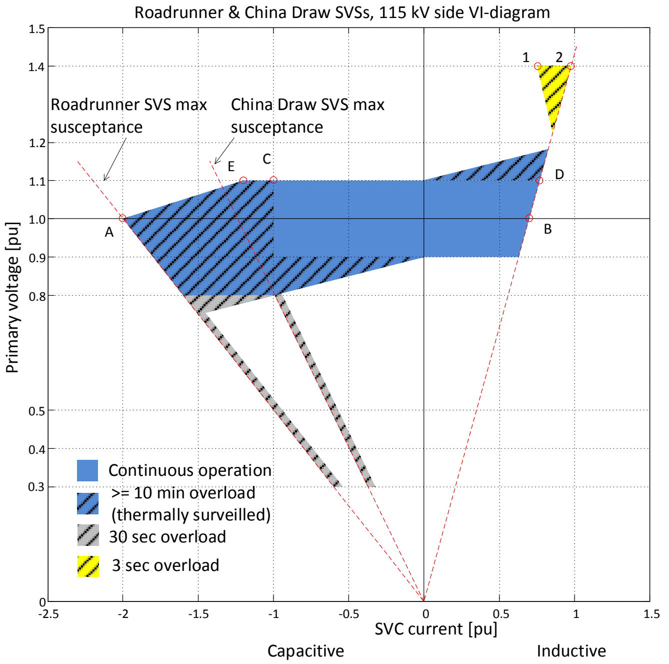

Figure 3. SVC 115 kV side Voltage – Current Characteristic

Not indicated in the VI characteristic in figure 3, is that the SVC controls nearby mechanically switched capacitors (MSC) to offset the SVC output during continuous operation. Each SVC controls two (2) 14.4-Mvar and three (3) 28.8-Mvar local 115-kV capacitor banks. The banks being referred to as local implies they are physically connected to the SVC point of interconnection to the 115-kV system. Provisions to add three (3) future local banks to the switching scheme are included. The bank control scheme is explained in section III together with the SVC control features.

III. OVERVIEW OF SVC CONTROL

A. *External Mechanically Switched Capacitor Control*

China Draw and Roadrunner each have five MSC banks assigned at the local 115-kV bus, where two are rated 14.4-Mvar and the remaining three 28.8-Mvar. The purpose of the SVC based local 115-kV shunt bank control is to preserve SVC dynamic range by utilizing the HV shunt banks to absorb daily voltage changes related to slow system load variation. This is implemented by coordinated deployment of shunt banks based on SVC susceptance threshold levels after a settable time delays, as show in figure 5.

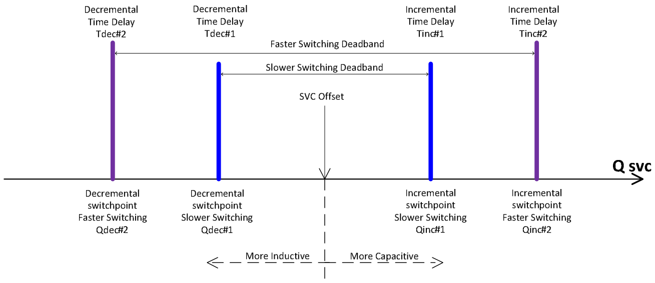

Figure 5. MSC bank control based on SVC susceptance.

The banks are switched according to a first in – first out sequence based, where the number of operations is monitored and kept equal between banks of equal rating. When inserting one bank does not bring the SVC back within the desired steady state operating range, the next available bank with the least number of operations is inserted. Switching delays and SVC threshold levels are selectable from the SVC HMI. Control schemes to prevent hunting and observe discharge time are implemented. The minimum time for subsequent insertion is adjustable. The banks can be selected for remote, operation independent from the SVS control system. If the SVS is taken out of service for any reason, the bank status will remain and control is seamlessly transferred to the dispatch center through the SCADA system.

Prior to switching, FLE action described in the next section is done to preserve system SCR integrity, where MSC switching is aborted and the bank(s) blocked if the fault level is found too low. Banks can also be switched out when the FLE detects a low SCR level. At the time the SVCs were placed in-service, severe curtailment was imposed at both sites.

B. *Advanced Fault Level Estimator Control*

It is evident from section II of this paper that knowledge of the approximate system fault level is crucial to maintain stability. The primary advanced control function used for this purpose is the Fault Level Estimator (FLE), which not only moderates the SVC controller gain, but also restricts operation of both TSC steps and externally controlled MSC banks at reduced fault levels. The working principle of the FLE is to produce two consecutive susceptance pulses (B_{ref}), one in the positive and one in the negative direction. The voltage response is used to calculate the fault level in MVA. An example FLE action with resulting gain adjustment is shown in figure 4.

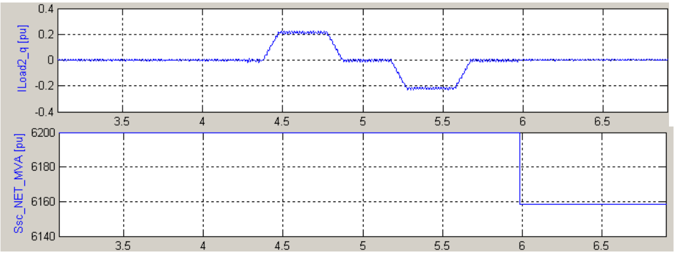

Figure 4. Resulting SVC current from a B_{ref} pulse and FLE output

System studies, verified by field testing, determine the ranges of available fault levels, where each is assigned individual gain values, as well as restrictions for operating MSC banks and TSC branches. Project stage studies looked at several different network scenarios assigned to planning cases of both 2016 and 2020. As load projections and plans change, SVC control settings must be revisited. For this purpose, detailed SVC software models were provided for use in PSSE and PSCAD.

The following activate the FLE operation:

- SVC start sequence
- MSC bank switching/blocking
- Local breaker status change (direct controller input)
- Gain Supervision
- Fast TSC Blocking [1], [2]
- Undervoltage Strategy
- Manual triggering, either through HMI or SCADA
- Automatic triggering, through an HMI setting

MSC bank blocking will initiate an automatic triggering of the FLE periodically after a selectable delay to prevent unnecessarily blocking MSCs over longer periods of time. Automatic triggering is also available separately with a default frequency of 120 minutes. The purpose of manual triggering is to force the SVC to adjust to the prevailing system strength during planned or long-term outages that may not otherwise trigger the function.

All triggers initiate the FLE with a time delay of 10 seconds to let the system stabilize in its current state before activation.

C. *Control Coordination of Nearby Installations*

Each SVS is designed to operate individually, with separate redundant control systems, protection systems and auxiliary power. However, there are plans for new transmission lines between Red Bluff and China Draw, making the two SVS units tightly coupled electrically. Project studies indicated that FLE precision would be severely reduced, if not rendered ineffective, by counteraction from the nearby SVC. To overcome this, a parallel operating scheme is utilized. The coordinated control scheme is implemented in the control software and hardware delivered, but requires optical fiber connection between the two sites.

During the control design stage, a parallel operating scheme was introduced and tested that involved the FLE. The coordination is primarily achieved during FLE action. When an SVC initiates the FLE, communication will cause the other SVC to retain its current output until the FLE sequence is completed. This way gain is selected locally at the individual SVC location as implemented in the control. Roadrunner has inherent priority should the SVCs simultaneously call for FLE action.

When set to active, the coordinated operation of the two SVS units is automatically activated if both are running in automatic voltage control mode. Automatic activation can be disabled during islanded situations where it is decided to operate the units independently with individual FLE.

As the system continues to develop, the parallel operating scheme will be extended to coordinate voltage control settings, such as slope and voltage reference. This will provide complete parallel operation between the SVCs. Based on the location and system topology surrounding the individual SVCs, it was decided the 115-kV shunt capacitor banks be controlled solely by the local SVC. This means that an SVC cannot control remote capacitor banks located at the other SVC. This is due to instances where a single contingency can significantly decouple the China Draw SVC from Roadrunner. For the same reason, regulator gain is not coordinated by means of the parallel operation scheme.

IV. OPERATING EXPERIENCE

The SVCs were placed in-service consecutively, Roadrunner late March and China Draw in late April 2016. One notable item is the harmonic monitoring, which is not a common practice for Xcel Energy. MSC banks tend to tune the system resonances at around the 5th harmonic frequency, evidenced by the elevated voltage distortion recorded before SVC installation. To mitigate amplification of background harmonics, each SVC was equipped with a 30-Mvar, 115-kV filter bank. The SVC heavily-damped, C-type primary filter is tuned to attenuate the existing parallel resonance, which was required to meet the specified IEEE 519 [3] recommended voltage distortion limits. This type of problem and how to address it is thoroughly described in [4].

With measured background 5th harmonic voltage distortion more than 5%, the SVC was looked at as the given remedy to the issue. Thorough analysis was performed looking at various filter designs with given network scenarios. Harmonic impedance scans were done, beyond those provided with the request for proposal. The adjacent bus at Red Bluff was analyzed, where the background measurements originated. System changes between 2016 and 2020 planning cases were compared and the future impact of the SVCs on system harmonic impedance could be evaluated. Harmonic amplification factors at the SVC point of interface to the 115-kV network must be close to unity for critical harmonic orders to achieve a robust design. By industry practice, modelling a harmonic source behind the worst-case network impedance allows for calculation of the maximum amplification at the SVC point of connection. This provides a conservative estimation that does not account for the multiple harmonic sources and characteristics found throughout a transmission system. It is, however, the only practical way to address the issue.

Even with this type of thorough analysis, the only conclusion possible to make and agree on was that the situation would likely improve with the measures taken related to the SVC installations. Even though amplification factors to some extent can be evaluated, it is not possible to predict future harmonic generation. Hence, what background levels to use when calculating the resulting distortion remains unknown. To verify the effectiveness of the filter design and its robustness to system changes, it was agreed to implement continuous harmonic monitoring at the Roadrunner SVC. Monitoring was initiated in November 2016 and reported monthly. Of interest are the characteristic harmonics up to the 17th order, particularly the 3rd, 5th and 7th orders. To date, these measurements have shown consistent levels well below recommended planning levels.

Apart from typical early life-cycle issues, both SVCs have performed well, primarily in automatic voltage control mode. Due to the environment, special consideration has been given to HVAC and cooling tower maintenance. The SVCs are at the remote ends of the Xcel Energy system in SE New Mexico, making the implementation of a remote desktop application indispensible to see detailed alarm conditions before deploying maintenance personnel.

V. CONCLUSION

Two Static Var Compensators have been deployed at 115-kV in South Eastern New Mexico. The transmission system sensitivity to an SVC admittance regulator control largely depends on the system fault level. For a strong system, the frequencies associated with the system eigenvalues are high enough to avoid interaction between the regulator and system, where the SVC is small in relation to the system fault level, i.e. the SCR is high. The challenge with a weak, heavily shunt compensated transmission systems is that the oscillatory frequencies show up in the range of interaction with the SVC controls. This is a factor when the size of the SVC capacitive range approaches the system fault level, i.e. the SCR is low. Advanced control functions and coordination in combination with a flexible SVC topology greatly increase operability of large SVCs in weak transmission systems. SVC adaptability to changes in the prevailing system fault level is key in this respect.

It can be mentioned that for the 2016 system conditions, the China Draw SVC could see effective SCR levels as low as

1.35, when considering that up to 100-Mvar shunt capacitor banks may be in-service. The low SCR conditions and related potential stability issues directly impact the maximum voltage regulator gain as well as the type of regulator used. It is also necessary to restrict the amount of SVC and shunt bank Mvar inserted in the system during certain specific conditions, including possible post fault overvoltage issues.

ACKNOWLEDGMENT

ABB would like to acknowledge Xcel Energy for support provided throughout the project and the writing of this paper.

REFERENCES

[1] Al-Mubarak, Bamsak, B. Thorvaldsson, M. Halonen, R. Grünbaum, "Preventing voltage collapse by large SVCs at power system faults," IEEE PES T&D Conference, 2009

[2] ABB AB, "SVC for voltage support of a 220 kV grid feeding mining loads in Western Australia," unpublished [Online]. Available: https://library.e.abb.com/public/8f6024ac82eaeda1482579c10057f1f1/1JNS010544%20LR.pdf

[3] *IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems,* IEEE Std. 519-2014

[4] Horton, Duggan and Hallmark, "Novel design methodology for c-type harmonic filter banks applied in HV and EHV networks," IEEE PES T&D Conference, 2012